

Assessing the validity of station location assumptions made in the calculation of the Geomagnetic Disturbance Index, *Dst*

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[1] In this paper, the effects of the assumptions made in the calculation of the *Dst* index with regard to longitude sampling, hemisphere bias, and latitude correction are explored. The insights gained from this study will allow operational users to better understand the local implications of the *Dst* index and will lead to future index formulations that are more physically motivated. We recompute the index using 12 longitudinally spaced low-latitude stations, including the traditional 4 (in Honolulu, Kakioka, San Juan, and Hermanus), and compare it to the standard United States Geological Survey definitive *Dst*. We look at the hemisphere balance by comparing stations at equal geomagnetic latitudes in the Northern and Southern hemispheres. We further separate the 12-station time series into two hemispheric indices and find that there are measurable differences in the traditional *Dst* formulation due to the undersampling of the Southern Hemisphere in comparison with the Northern Hemisphere. To analyze the effect of latitude correction, we plot latitudinal variation in a disturbance observed during the year 2005 using two separate longitudinal observatory chains. We separate these by activity level and find that while the traditional cosine form fits the latitudinal distributions well for low levels of activity, at higher levels of disturbance the cosine form does not fit the observed variation. This suggests that the traditional latitude scaling is insufficient during active times. The effect of the Northern Hemisphere bias and the inadequate latitude scaling is such that the standard correction underestimates the true disturbance by 10–30 nT for storms of main phase magnitude deviation greater than 150 nT in the traditional *Dst* index.

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1. Introduction

[2] The Disturbance storm-time index (*Dst* index) is commonly used as a global indicator of the state of the Earth's geomagnetic activity level for space weather research and operations. Originally developed by Sugiura *et al.* [1964], the index specifies the variation in the horizontal component of the Earth's magnetic field, measured at four ground-based observatories: Honolulu, Kakioka, San Juan, and Hermanus. The index is used to define levels of geomagnetic disturbance and is sometimes interpreted as the ground-level magnetic perturbation due to symmetric ring current enhancements that occur during geomagnetic storms. Other versions of the *Dst* index have been produced with the same basic intent, namely, to describe external magnetic field variations and

encapsulate aspects of global geomagnetic disturbance with a single number. These include the U.S. Geological Survey (USGS) *Dst* [Love and Gannon, 2009; Gannon and Love, 2010], the DCX index [Mursula and Karinen, 2005; Karinen and Mursula, 2006], and RDst [O'Brien and McPherron, 1999].

[3] The *Dst* index is widely used not only as an indicator of storm levels and phases but also as input into magnetic field models [e.g., McCollough *et al.*, 2008; Pulkkinen *et al.*, 2006], as a discriminator in scientific studies [e.g., Reeves *et al.*, 2003], and as an alert level for satellite systems operators. Its accuracy is therefore an important issue to the space physics and operations communities. However, as indices are derived quantities, not physical ones, we cannot validate or assess accuracy by direct comparison to measurable values. In other words, because an index is derived instead of measured, we have no absolute baseline with which to compare. We can only assess how our choices in algorithm assumptions change the final result.

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[4] Modern versions of the *Dst* index rely on many of the same basic assumptions. The first is that any global ring current variation is seen uniformly at all longitudes, and any non-global local time effects are effectively averaged out by selecting evenly spaced stations. Longitudinal variation in magnetic field strength are shown in *Love and Gannon* [2010] to be highly asymmetric during geomagnetic activity. However, even though using more stations could increase accuracy in terms of a global average, data management issues become increasingly difficult; so using the fewest number of stations that adequately capture global variation is important.

[5] The next assumption is that there is no difference between the Northern and Southern hemispheres in terms of storm-time variation. This assumption suggests that complementary points in the Northern and Southern hemispheres are equidistant from ionospheric disturbances, ring current enhancements and equatorial perturbations, and there should therefore be no difference between the hemispheres. If these points are of equal invariant latitude, or the same surface crossing point of a single field line, then any particle population or external magnetic field variation should evenly propagate in both directions and be measured at both locations. Reality is more complicated and less symmetric. This assumption can be fairly difficult to test, as most stations do not have conjugate stations in the opposite hemisphere. In fact, the conjugate points of most of our North American USGS stations would be in the middle of the Southern Pacific ocean.

[6] Another assumption that has been commonly used is the idea that we can simply scale disturbance from one latitude to another using a constant scaling factor. Usually, the cosine of the invariant latitude is used, and each station is multiplied by this factor to scale to the geomagnetic equator. At the same time, we avoid using stations on the geomagnetic equator due to equatorial electrojet effects causing non-ring current deviations which would perturb our time series.

[7] There are additional assumptions inherent to the way that scientists and operators use *Dst*, including the accuracy of the index in representing ring current enhancements. It has been shown that induced crustal currents can contribute up to 30% to ground-based magnetic variations during storms [e.g., *Anderssen and Seneta*, 1969]. There are also measurable effects in components other than the horizontal magnetic field intensity, such as declination variation, that are important to a comprehensive understanding of the effect on the ground due to ring current fluctuations. The choice of method additionally has an impact on the final *Dst* result. In this paper, we use the USGS *Dst* calculation method, which was evaluated in *Love and Gannon* [2009], as well as *Gannon and Love* [2010]. Although these assumptions are important to understand when interpreting storm-time magnetic field variations, we do not consider them here, as it is difficult to assess physical accuracy without direct measurement of the ring current as a basis for comparison. In this paper, we study

several station location assumptions common to all versions of *Dst*, including the number of stations, hemisphere bias, and latitude correction.

2. U.S. Geological Survey *Dst* Method

[8] The USGS *Dst* is produced through a combination of time and frequency space analyses (detailed in *Love and Gannon* [2009] and *Gannon and Love* [2010]). A quiet time curve baseline subtraction is done by fitting a Chebyshev polynomial to quiet periods in the time series, effectively detrending the data set. This removes the slowly varying crustal field contributions, or secular variation components. The solar quiet variation is then estimated by transforming the time series (with large storm contributions removed) into frequency space, where components of known frequencies are identified and removed. Through this series of steps, a time series of magnetic field disturbance values is obtained for each of the 4 contributing stations. These are then weighted by magnetic latitude and averaged, yielding the *Dst* index.

[9] The data used in this study are 1-min resolution horizontal intensity time series from various ground-based magnetic observatories enumerated later, obtained from Intermagnet (www.intermagnet.org). These data are definitive, processed values, where baseline offsets, spikes, and other artificial anomalies have been removed. For this study, we use data from 2004–2008. The filter parameters are tuned to this length of time, following the techniques used for the calculation of the USGS definitive *Dst* index.

[10] Although we use the USGS *Dst* index method, this analysis could be applied to any formulation of *Dst* using the same magnetic field data as input. Independent of method selection, we look at general properties of the measured disturbance at individual observatory locations to analyze the possible impact of input selection and biases.

3. Station Inclusion

[11] The first assumption we test is how the number of included stations impacts the *Dst* index. If using 4 stations adequately samples global storm time geomagnetic disturbance, then adding more stations in a symmetric way will not greatly improve the result. *Love and Gannon* [2010] or *Gjerloev et al.* [2003] suggest that there is a larger longitudinal asymmetry during storms than is commonly assumed, and therefore the sparse sampling provided by 4 stations may not be sufficient to capture the nature of storm-time signals at the ground. We calculate a 12-station *Dst*, adding 8 more stations to the traditional 4 (in Honolulu, Kakioka, San Juan, and Hermanus) in a low-latitude, evenly spaced longitudinal pattern. The observatories are listed in Table 1, and their locations are shown in the map in Figure 1; they include the original 4 stations used to calculate *Dst*.

[12] The black curve in Figure 2a shows the 12-station *Dst* compared to the traditional 4-station *Dst* calculated over the

Table 1. Stations Used in a 12-Station *Dst* Index Calculation, Separated by Hemisphere^a

Station	Name	Mag Lat	Mag Long	Program
			<i>North</i>	
ABG	Alibag	10.19	146.16	Indian Institute of Geomagnetism
<i>HON</i>	<i>Honolulu</i>	<i>21.64</i>	<i>269.74</i>	<i>U.S. Geological Survey</i>
KAK	Kakioka	27.37	208.76	Japan Meterological Agency
MBO	M'Bour	20.11	57.47	Institut de Recherche pour le Developpment
<i>SJG</i>	<i>San Juan</i>	<i>28.31</i>	<i>6.08</i>	<i>U.S. Geological Survey</i>
TUC	Tucson	39.88	316.11	U.S. Geological Survey
			<i>South</i>	
API	Apia	-15.36	262.66	Department of Agriculture, Forestry, Fisheries and Meteorology of Western Samoa
LRM	Learmouth	-32.42	186.46	Geoscience Australia
<i>HER</i>	<i>Hermanus</i>	<i>-33.98</i>	<i>84.02</i>	<i>National Research Foundation of South Africa</i>
PPT	Papeete	-15.14	285.14	Institut de Physique du Globe de Paris
TAN	Tananarive	-23.67	115.78	Institut et Observatoire Geophysique d'Antananarivo
VSS	Vassouras	-13.29	26.61	Observatorio Nacional

^aThe four traditional *Dst* stations are shown in italics.

same time period. The green curve is the point-by-point difference between the 12-station and the 4-station indices. The average difference is 0.3 nT for this 4-yr time period, which suggests that adding the additional observatories to the index does not change the magnitude of the result greatly, although at points the difference is nearly 10 nT. The

closer views in Figures 2b and 2c show that the greatest differences occur during storm periods, as we might expect (in this example, 20–30 nT). Values during quiet times should be fairly uniform from location to location and easily corrected for by the baseline subtraction, whereas the differences in observatory location will more strongly

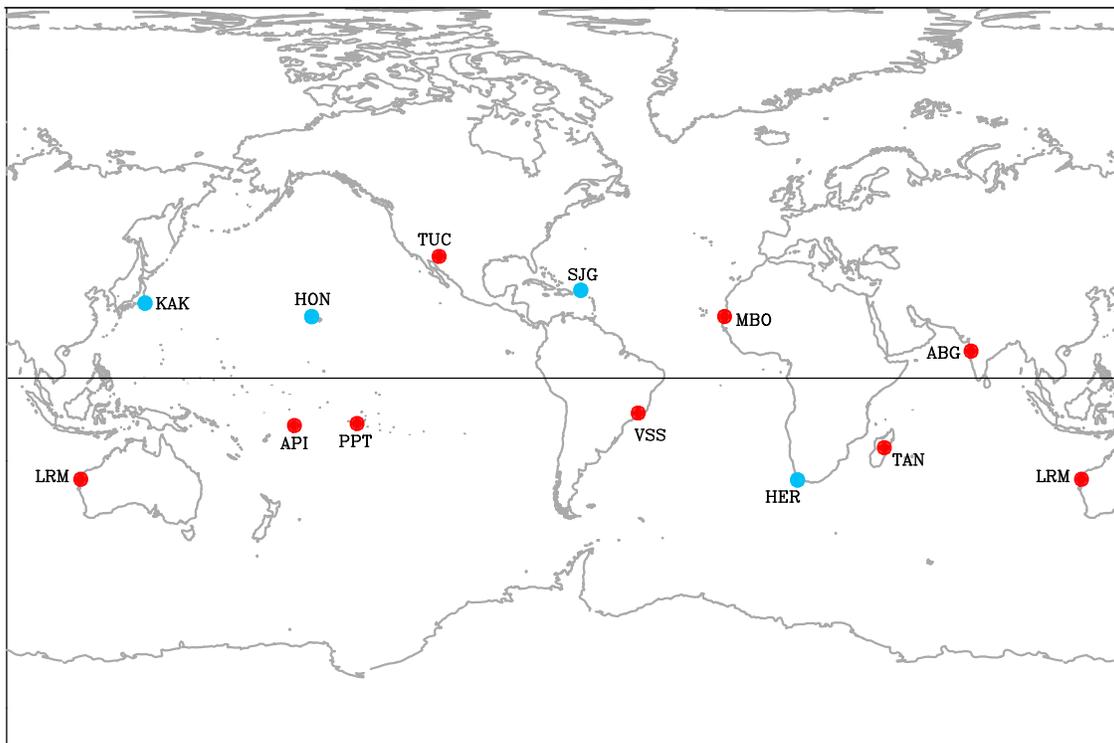


Figure 1. Map of stations used in the 12-station *Dst* index, the hemisphere observatory pairs, and the two chains of observatories used for latitude distributions of disturbance.

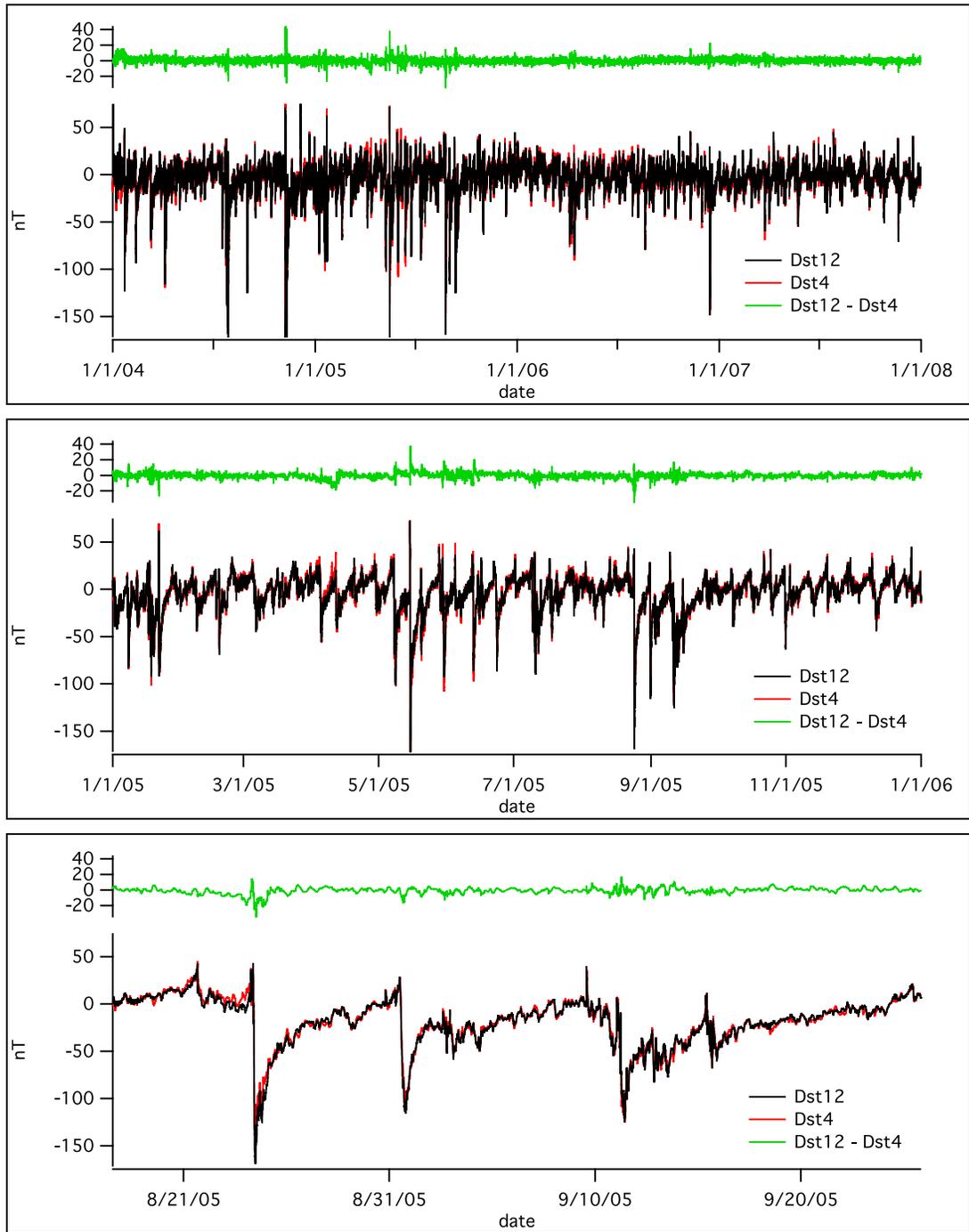


Figure 2. Twelve-station *Dst* index. The black curve in each panel is the 12-station index superimposed on the USGS Definitive *Dst* in red. The green trace is the point-by-point difference between the two, offset by 50 nT for clarity. (top) The entire 4-yr analysis time span, (middle) a single year example, and (bottom) a storm-time example. Dates are specified as mm/dd/yy.

Table 2. Stations Used for Hemisphere Pairs

Station	Name	Mag Lat	Mag Long	Observatory Program
SPT	San Pablo-Toledo	42.78	75.98	Instituto Geografico Nacional
LRM	Learmouth	-32.42	186.46	Geoscience Australia
BMT	Beijing Ming Tombs	30.13	187.04	Chinese Academy of Sciences
HER	Hermanus	-33.98	84.02	National Research Foundation of South Africa

influence the final result during storm time due to proximity to local and ionospheric current system enhancements [e.g., *Campbell, 1996; Friedrich et al., 1999*]. Because storm periods are of greater interest to the space weather community than quiet times, it is the excursions that are more important than the average difference in analyzing whether more stations would help to better specify magnetospheric disturbance. A difference of 10 nT (7–10% of the 100–150 nT storm deviation) between the 4-station and 12-station index during storms is a small but measurable effect and suggests that the inclusions of more stations in the *Dst* index would provide a better picture of average global disturbance.

4. Hemisphere Balance

[13] Next we investigate the impact of the Northern Hemisphere bias present in the traditional 4-station *Dst* index. Three stations (HON, SJG, and KAK) are located in the Northern Hemisphere, and only 1 is positioned in the Southern Hemisphere (HER). With the high density of observatories in Europe and North America, that the bias exists is not so surprising, but it is a generally untested assumption that geomagnetic disturbance will be symmetric at opposite geomagnetic latitudes. However, it is possible that different geophysical structures within the crustal regions of the Earth could contribute to variations in induced currents between the Northern and Southern hemispheres, producing a bias in disturbance measurements. The 12-station index that we composed includes 6 stations in the Northern Hemisphere and 6 stations in the Southern Hemisphere, so the differences between the index and the traditional formulation may be caused by a north-south bias rather than any longitudinal asymmetry, or by a lack of global coherence in disturbance patterns. We test this assumption by selecting pairs of stations on similar longitudes in the opposite hemisphere, and similar latitudes in the same hemispheres, to examine if disturbances measured in the North are really the same as disturbances measured in the South. The stations we select are LRM, SPT, HER, and BMT. Their locations are given in Table 2 and shown in Figure 1.

[14] The ratio of disturbance observed at the pairs of stations (depicted in Figure 3) is taken to show the applicability of a constant multiplicative scaling factor, such as is used in the traditional latitude scaling. The traditional scaling is applied by multiplying the cosine of the magnetic latitude to the disturbance at a particular observatory. The scaling factor is the same for an observatory in

the Northern and Southern hemispheres. Considering the ratio from observatories at equal but opposite magnetic latitudes, if the disturbance values vary perfectly together, the ratio should be a constant value.

$$D_N \cos \theta_N = D_S \cos \theta_S$$

$$\frac{D_N}{D_S} = \frac{\cos \theta_S}{\cos \theta_N} = C$$

where D_N is the disturbance at the Northern Hemisphere observatory, D_S is the disturbance value at the Southern Hemisphere observatory, and θ_N and θ_S are the corresponding magnetic latitudes. If the latitudes are identical, the constant C should be equal to 1.

[15] Figure 3 shows the ratios of the two pairs of stations on the same longitude, opposite latitudes during a storm period in 2005. The ratio is clearly not constant. It should be noted that using the ratio overemphasizes differences during low levels of disturbance because the relative variation is higher. It is during these times that the inaccuracy matters the least, as the scaling factor is near 1, and is being multiplied by very small magnitude disturbance. However, it is during these times that we would expect the scaling to work well. In many cases when comparing the disturbance at two observatory locations, there are local time or longitudinal effects to also be considered. In this case, because the station pairs are located on the same longitudes, the differences can not be related to local time variations, but must be due to other latitude asymmetries or local effects. This reinforces the concept that the magnetic field of the Earth is complicated, especially during a geomagnetic disturbance, and scaling from one location to another is a difficult proposition, possibly one not best accomplished with a single scaling factor.

[16] We investigate possible hemisphere-bias effects by dividing the 12-station index into two separate indices based on data from the Northern and Southern hemispheres separately, with 6 stations each, as listed in Table 1. Figure 4 shows these two time series in red and black, respectively, as well as the difference between them in green. The average difference is small, -0.3 nT, but the instantaneous deviation can be large, nearly 50 nT. The difference is noted to be greater during storms, with the Southern Hemisphere tending to a lower value from the sudden commencement through the main phase. This suggests that there can be significant differences

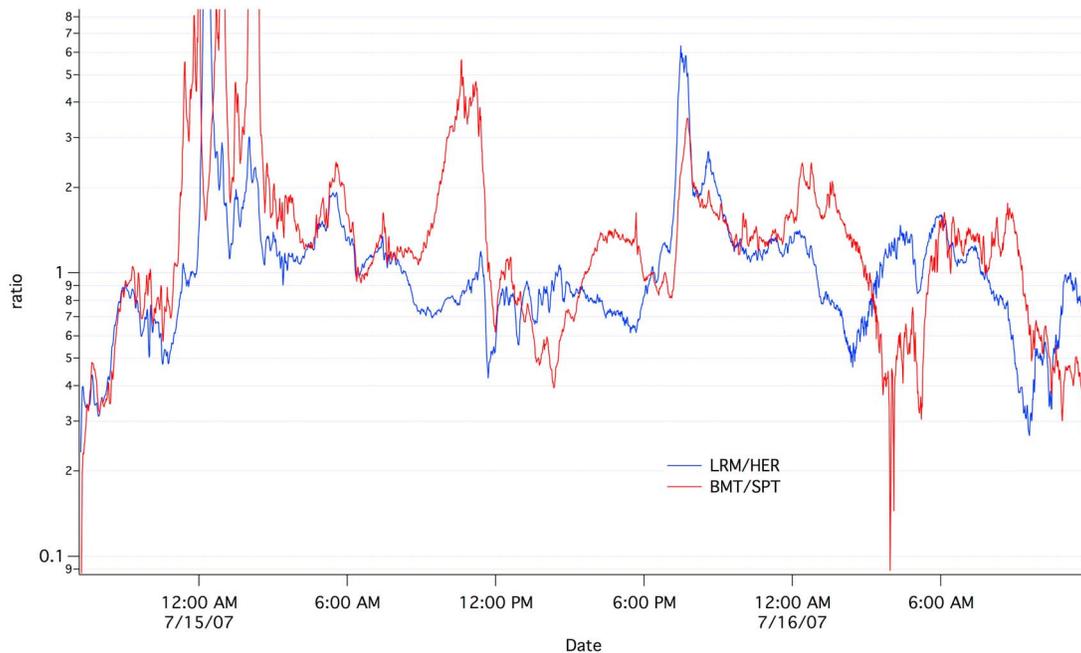


Figure 3. An example of the ratio of disturbance values measured at observatory pairs. BMT/SPT shows the ratio of observatories at a similar longitude but at opposite hemisphere latitudes. LRM/HER shows the ratio of the observatories at a similar latitude in the same hemisphere.

between the Northern and Southern hemispheres during times of geomagnetic activity. However, it cannot tell us if these differences are adequately sampled by the traditional 4 stations.

[17] To determine how well the traditional 4 stations capture Northern and Southern Hemisphere variability, we compare the 6-station Northern and Southern indices to the Northern and Southern components of the 4-station index. From Figure 5, which shows the same example time period as Figure 4, we see that the differences between the Southern components are larger and more variable than the differences between the Northern components. This suggests that a main component of the difference between the 12-station and the 4-station index could be due to inadequately sampling the Southern Hemisphere. However, it could also be a symptom of greater localized fluctuations in the Southern Hemisphere.

[18] The normalized histograms shown in Figures 6a–6c further illustrate the differences between Northern and Southern Hemisphere sampling. Using only HER in the 4-station formulation appears to underrepresent the full distribution of Southern activity levels, whereas the 3 stations in the north adequately sample the full distribution. In addition, the trend shown in Figure 6 seems inconsistent with the interpretation that the Southern Hemisphere tends to lower values, as the blue trace

(Northern Hemisphere) falls inside that of the red trace (Southern Hemisphere) on the positive side of the distribution and outside on the negative side of the distribution.

[19] There are other reasons to consider the impacts of the hemispheric bias apart from sampling the full probability distribution of activity. Figure 7 shows a time period during which the Northern and Southern hemispheres (shown in red and black) respond oppositely to a period of activity. Because the positioning of the contributing observatories in the 4-station index (shown in green) favors the Northern Hemisphere, the response of the index favors the Northern Hemisphere response, whereas the 12-station version (shown in blue) has the effect averaged out. Neither of these are necessarily correct. In fact it is possible that the bias in index formulation actually allows us to see a real physical response that would otherwise be lost, but the influence on the final result is clear. Based on this analysis, the effect of Northern Hemisphere bias on *Dst* would be to underrepresent true storm strength.

5. Latitude Correction

[20] In this section we analyze how the variation in latitude of the contributing observatories could affect the *Dst* calculation. The observed differences in hemispheric disturbance discussed in the previous section may be due not

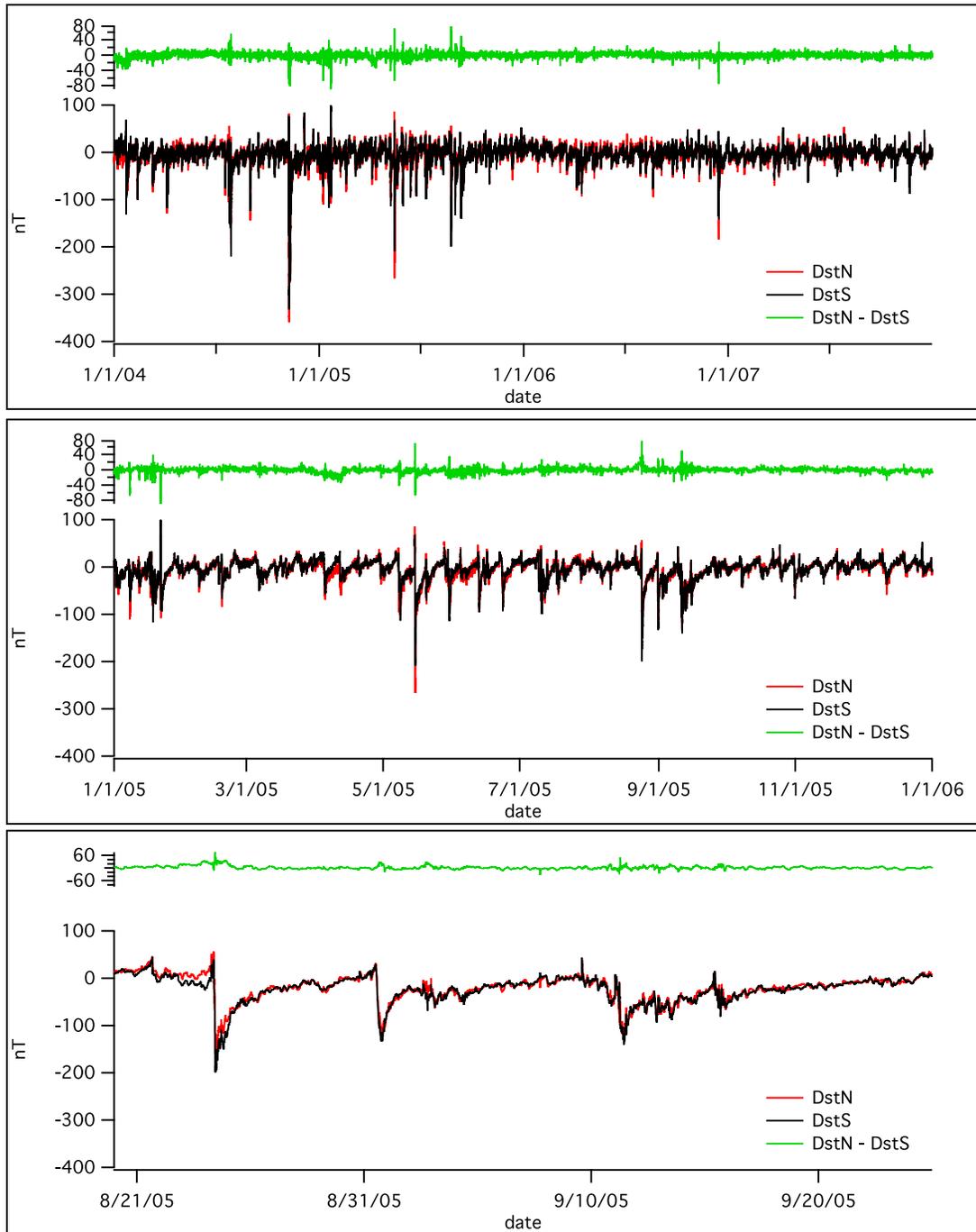


Figure 4. Comparison of Northern and Southern Hemisphere indices. The black curve in each panel is composed of 6 Northern Hemisphere observatories, superimposed on the index composed from 6 Southern Hemisphere observatories in red. The green trace is the point-by-point difference between the two, offset by 50 nT for clarity. (top) The entire 5-yr analysis time span, (middle) a single year example, and (bottom) a storm-time example. Dates are specified as mm/dd/yy.

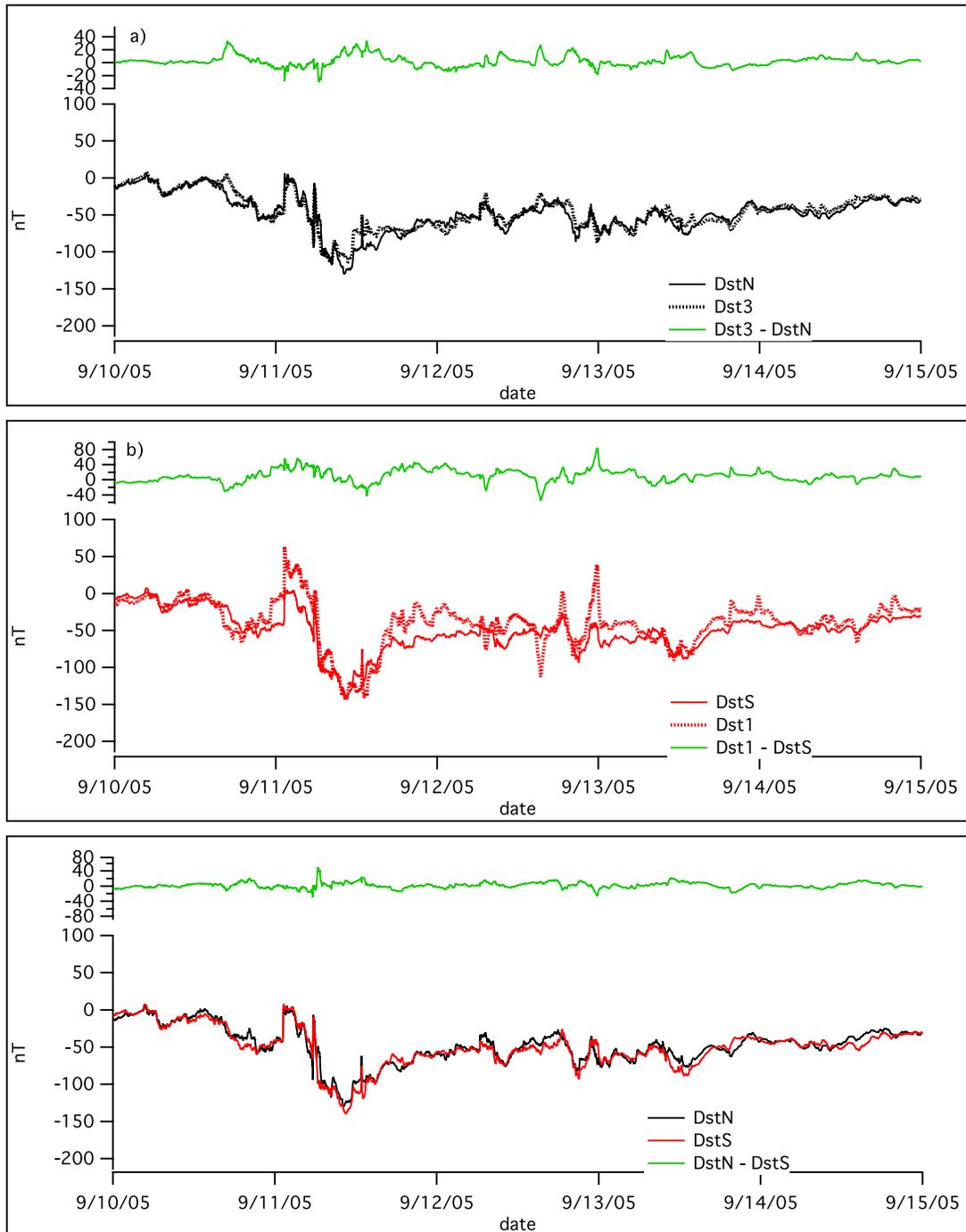


Figure 5. Comparison between the traditional components of the *Dst* index and the 6-station Northern and Southern indices. (a) The 6-station Northern index superimposed on an index derived from the 3 Northern Hemisphere components of the traditional 4 stations. (b) The 6-station Southern index superimposed on an index derived from the 1 Southern Hemisphere component of the traditional 4 stations. (c) The difference between the 6-station *DstN* and the 6-station *DstS*, for comparison. The green trace in each panel is the point-by-point difference between the two, offset by 50 nT for clarity. Dates are specified as mm/dd/yy.

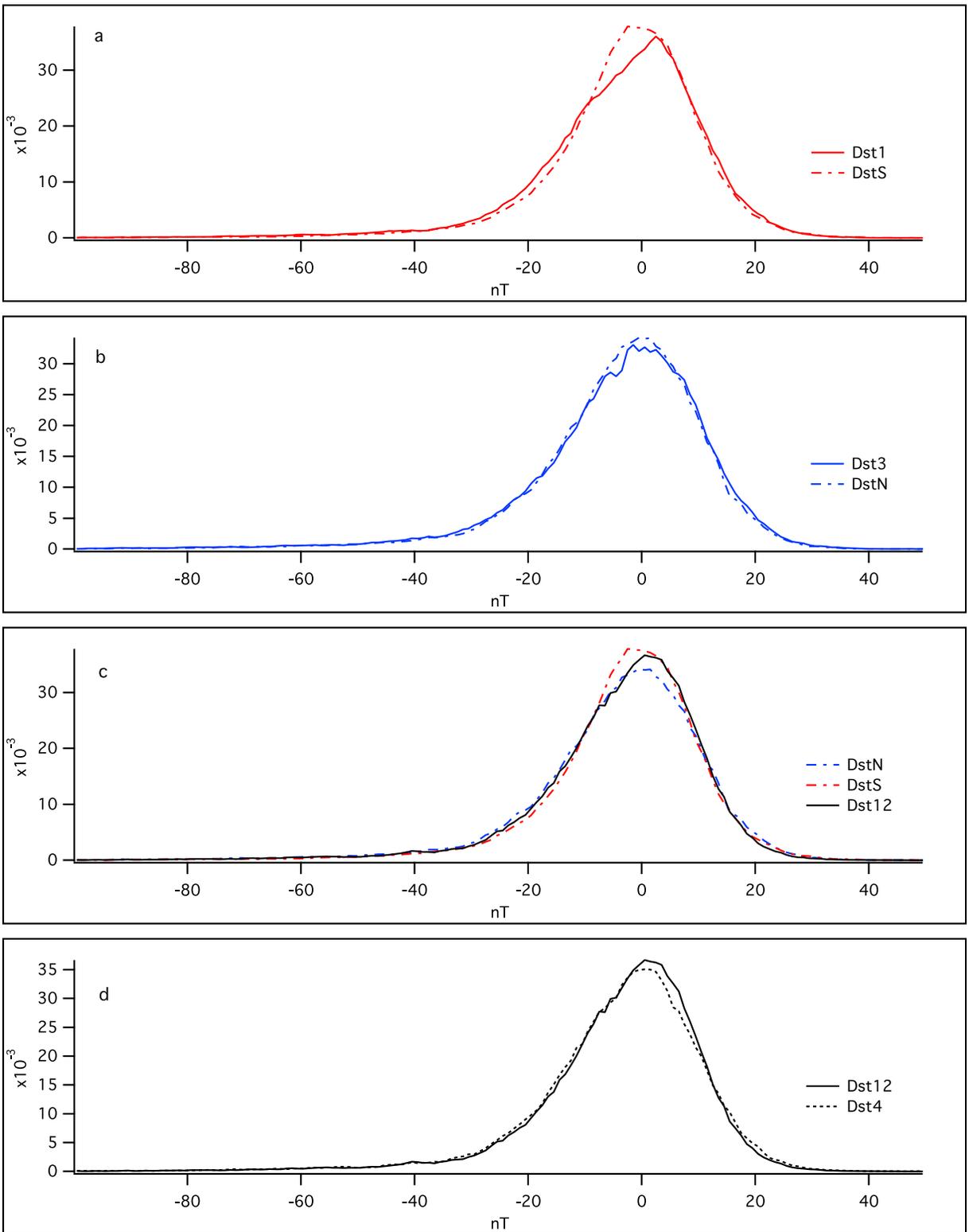


Figure 6

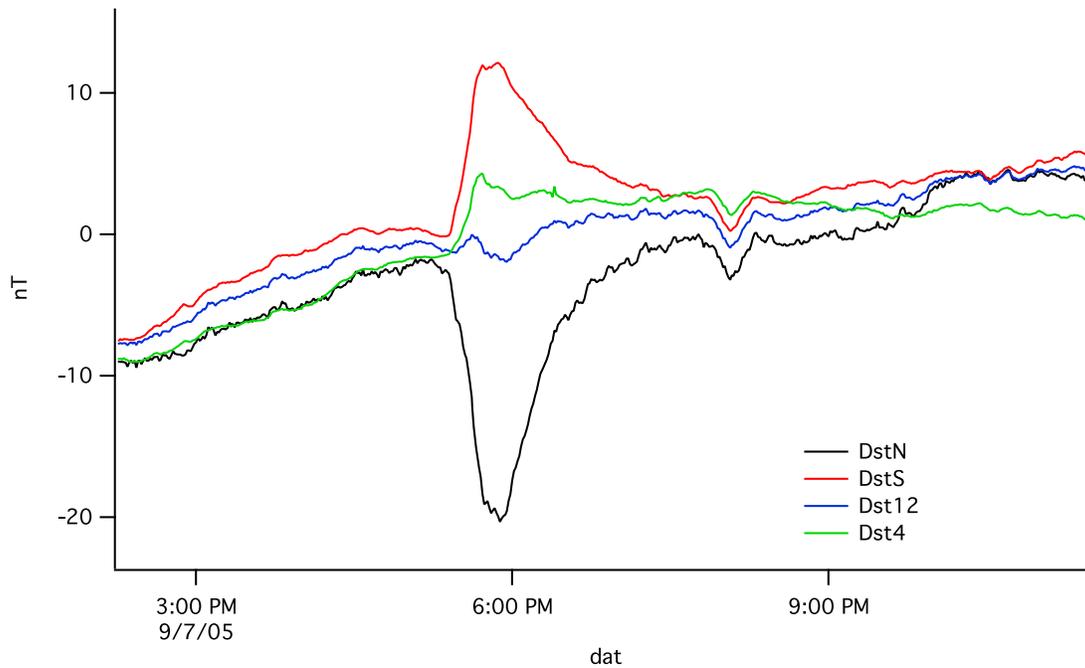


Figure 7. An example of the variational differences seen in the Northern (gray) and Southern (red) hemispheres and their impact on the 4-station (green) and 12-station (blue) indices. This shows the impact of a hemisphere-biased index during this example time period. Dates are specified as mm/dd/yy.

to any inherent physical differences but instead to the way in which latitude correction is treated. The 6 Northern Hemisphere stations used in this analysis have a slightly higher average magnetic latitude than the 6 Southern stations; therefore, if the scaling does not accurately reflect how disturbance varies with latitude, the hemisphere comparison will be skewed with respect to each other.

[21] To test this hypothesis, we carefully selected stations along the same longitude, in a chain from south to north. Two such chains were selected for the availability of data in the year 2005. These chains are summarized in Table 3 and depicted in Figure 1. We averaged the disturbance levels over this year for each station, further separating by activity level as determined by the 12-station *Dst* index. The results are shown in Figure 8.

[22] The traditional latitude scaling is a simple cosine form of magnetic latitude. It is symmetric in magnetic latitude and not dependent on geomagnetic activity level.

The assumption that we are testing is whether the actual latitudinal variation of geomagnetic disturbance follows the same description. This variation is affected by the observatory's proximity to auroral or equatorial ionospheric current systems. The effects on the magnetic field due to these sources are complex and not necessarily symmetric, which is why high-latitude, midlatitude, and equatorial stations are typically not used in most *Dst* calculation methods. This restriction is shown to be well-justified in Figure 8, as the shape of the latitude variation changes significantly with activity level due to increased high-latitude and equatorial disturbance.

[23] To test whether a simple scaling based only on magnetic latitude works for *Dst* calculations, we must look only at those lower latitude stations. In Figure 9 we separate the curves from Figure 8 (bottom) into 6 panels and compare them to the cosine function that is assumed to describe them, for a smaller latitude range. Other than the

Figure 6. Comparison between the normalized histograms of the traditional components of the *Dst* index and the 6-station Northern and Southern indices. (a) The 6-station Southern index superimposed on an index derived from the 1 Southern Hemisphere component of the traditional 4 stations. (b) The 6-station Northern index superimposed on an index derived from the 3 Northern Hemisphere components of the traditional 4 stations. (c) The Northern and Southern distribution functions compared to that of the complete 12-station *Dst* index. (d) The distribution functions of the 4-station *Dst* versus the 12-station *Dst*.

Table 3. Observatories Used in Latitude Scaling Study

Station	Name	Mag Lat	Mag Long	Observatory Program
AIA	Argentine Island	-55.06	5.49	National Antarctic Scientific Center of Ukraine
FRD	Fredricksburg	48.40	353.38	U.S. Geological Survey
HUA	Huancayo	-1.80	356.54	Instituto Geofisico del Perce
IQA	Iqaluit	73.98	5.24	Geological Survey of Canada
KOU	Kourou	14.89	19.66	Institut de Physique du Globe de Paris
PBQ	Poste-de-la-Baleine	65.46	351.81	Geological Survey of Canada
PST	Port Stanley	-41.69	11.50	British Geological Survey
SJG	San Juan	28.31	6.08	U.S. Geological Survey
STJ	St. Johns	57.15	24.01	Geological Survey of Canada
THL	Qanaq	87.68	14.16	National Space Institute at the Technical University of Denmark
TRW	Trelew	-33.05	5.62	Universidad Nacional de la Plata
VSS	Vassouras	-13.29	26.61	Observatorio Nacional
ABK	Abisko	66.06	114.66	Geological Survey of Sweden
AAE	Addis Ababa	5.32	111.76	Institut de Physique du Globe de Paris
AQU	L'Aquila	42.42	94.50	Istituto Nazionale di Geofisica e Vulcanologia
BFE	Brorfelde	55.45	98.48	National Space Institute at the Technical University of Denmark
BDV	Budkov	48.77	97.61	Geophysical Institute, Academy of Sciences of the Czech Republic
CZT	Crozet	-51.35	113.27	École et Observatoire des Sciences de la Terre
HER	Hermanus	-33.98	84.02	National Research Foundation of South Africa
HLP	Hel	53.24	104.63	Institute of Geophysics Polish Academy of Sciences
HRB	Hartebeesthoek	46.87	101.11	Geophysical Institute of Slovak Academy of Sciences
NCK	Nagycenk	46.90	99.62	Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences
NGK	Niemegk	51.88	97.64	GeoForschungsZentrum Potsdam
UPS	Uppsala	58.51	106.30	Geological Survey of Sweden
TAM	Tamanrasset	24.66	81.76	Centre de Recherche en Astronomie, Astrophysique et Geophysique
TAN	Tananarive	-23.67	115.78	Institut et Observatoire Geophysique d'Antananarivo
THY	Tihany	45.99	100.47	Eotvos Lorand Geophysical Institute of Hungary

equatorial station HUA (which is included for completeness), the storm-time response of the magnetic field at these latitudes is considered to be dominated by magnetopause and ring current changes rather than ionospheric currents [Russell *et al.*, 1992]. For low levels of activity, both positive and negative (approximately 15 nT to -60 nT), the cosine form fits very well. *Dst* values are very often near zero, when this scaling is most appropriate. For storm-time values of interest, the cosine form does not appear to hold at all, and in both longitudes, the Southern Hemisphere appears to have a lower average value than the Northern Hemisphere. Because of this asymmetric disturbance effect, the Northern Hemisphere bias in *Dst* would contribute even further to underrepresenting true storm strength. If more Southern Hemisphere observatories contribute to the index, the lower values during storm time would lower the *Dst* measure by an additional 20–30 nT during larger storms ($|Dst| > 150$ nT).

6. Summary

[24] There are many factors, from physical processes to choices made in algorithm development, that may influence the magnetic disturbance levels described by the *Dst* index. However, any developer of a *Dst* method must make a decision about which observatories to include. In this paper, we analyze the validity of the assumptions that may contribute to the choice of observatories selected for

an algorithm, including the number of stations, hemisphere bias and latitude correction. We find that the inclusion of additional stations in the *Dst* index calculation produces small differences in the final result but may help balance out hemispheric bias, which appears to have a measurable impact. The variation between indices formulated solely from the Northern and Southern components may be most largely affected by the assumed latitude scaling, which does not hold at higher levels of activity and is not symmetric between the two hemispheres. The combined effect of Northern Hemisphere bias and overly simplified latitude correction yields a storm-time representation in which the main phase magnitude is lower than in reality by 10–30 nT during large ($|Dst| > 150$ nT) storms. This effect is more pronounced with increased storm magnitude.

[25] The *Dst* index has a long and valuable history, and this analysis does not contradict its use in operations. However, understanding the biases in the *Dst* index can aid operational users in interpreting global disturbances locally, taking into account that disturbance at higher latitude locations may be underestimated by the traditional *Dst* formulation. In addition, as computing power increases and the operational necessity for simplifying disturbance indices decreases, the design of future global indices should be formulated to better address these biases, through balanced hemisphere station inclusion and more realistic latitude corrections.

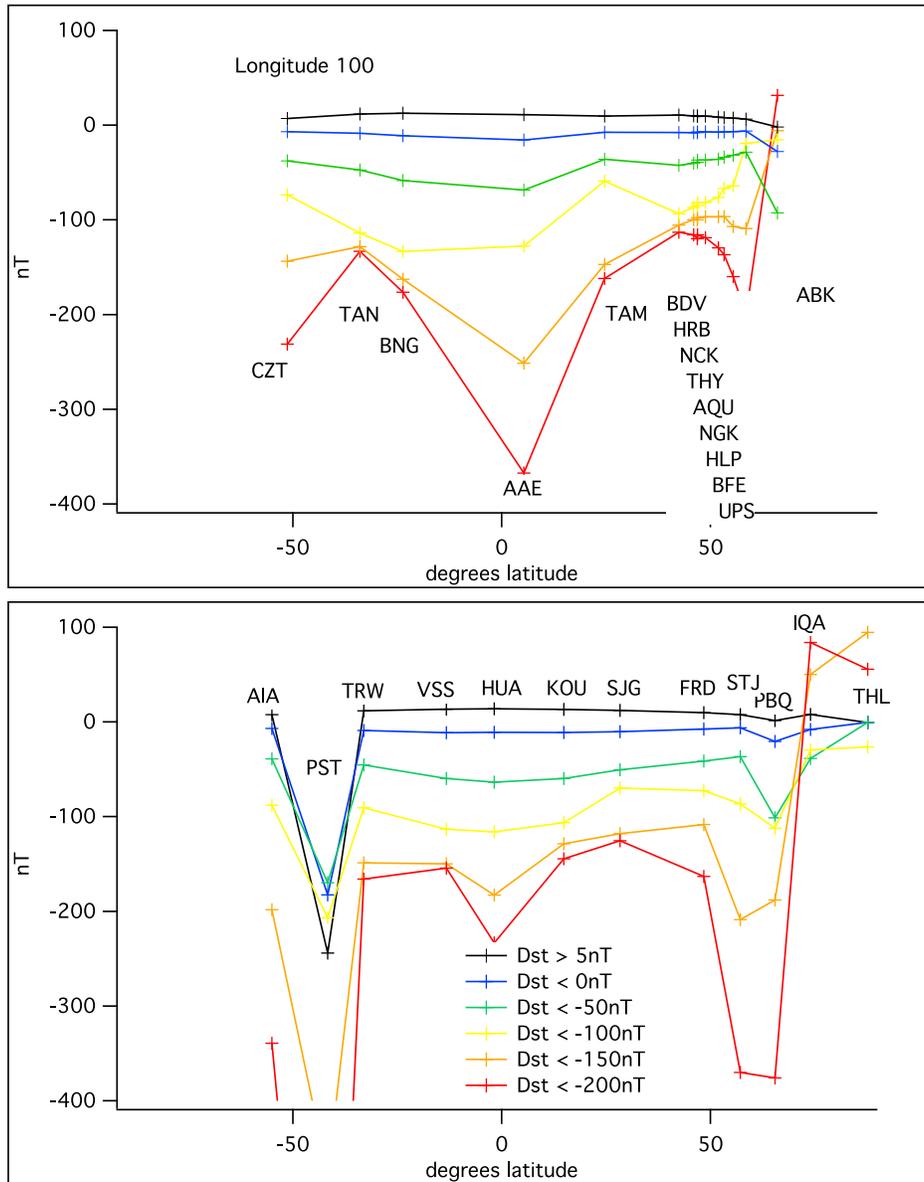


Figure 8. The latitudinal distribution of disturbance, separated by levels of the 12-station *Dst* index. The two panels show different chains of observatories on approximately similar latitudes.

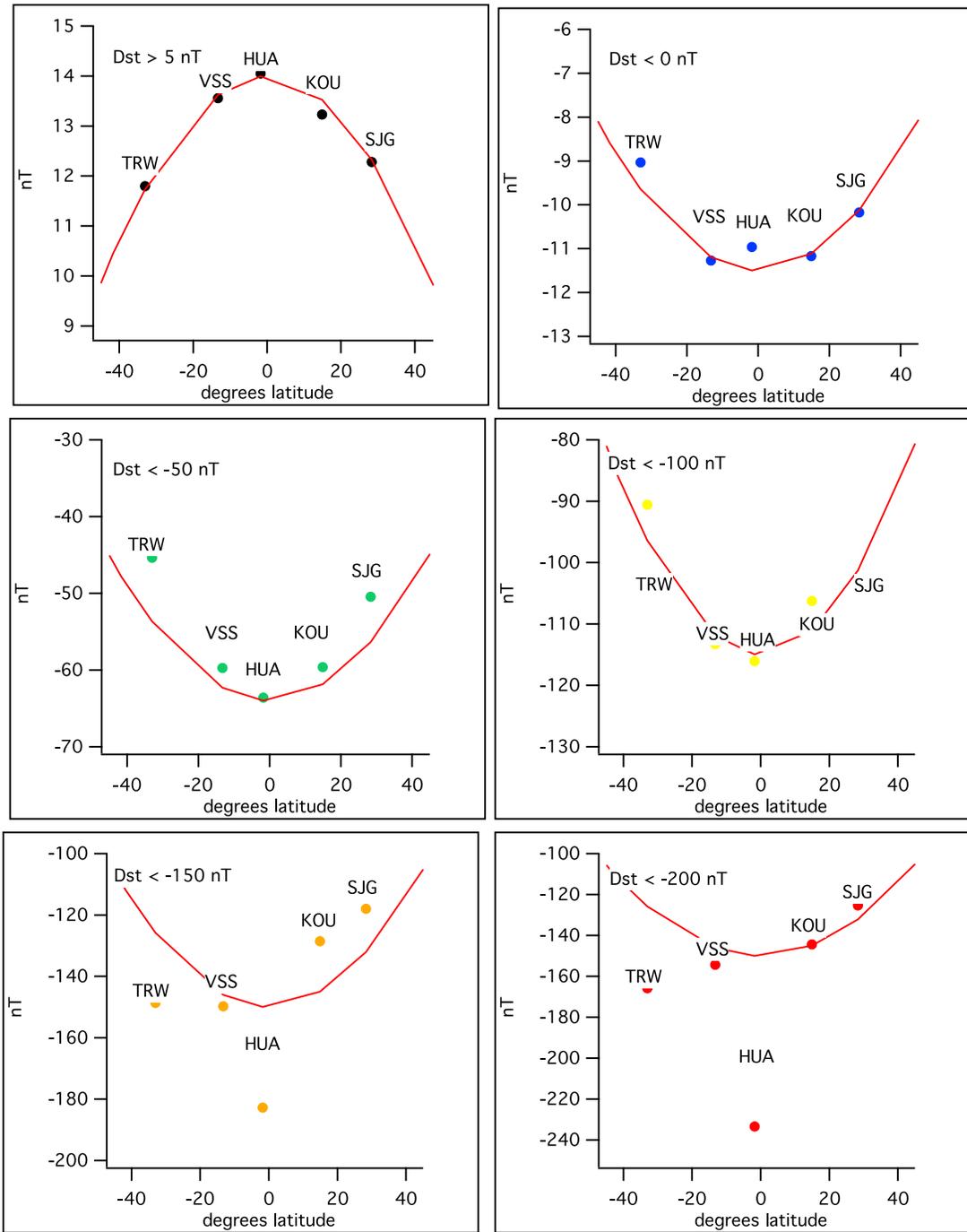


Figure 9. Each curve from Figure 8 (bottom), plotted separately and overlaid with an example cosine form representing the traditional latitude scaling.

[26] **Acknowledgments.** The results presented in this paper rely on data collected at magnetic observatories. We thank the national institutes that support them and INTERMAGNET for promoting high standards of magnetic observatory practice (www.intermagnet.org). Thanks also to J. McCollough, N. Farr, T. Carranza-Fulmer, and M. Moschetti for helpful discussions, and to C. A. Finn, E. W. Worthington, and E. So for reviewing a draft manuscript.

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